Craniofacial and alveolar bone changes

in young adults :

A 4-year longitudinal study

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Craniofacial and alveolar bone changes in young adults : A 4-year longitudinal study

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감사의 글

논문이 완성되기까지 따뜻한 배려와 함께 세심한 지도와 격려를 아끼지 않으신 황충주 지도 교수님께 진심으로 감사드리며, 귀중한 시간을 내주시어 논문 심사위원을 맡아주시고 부족한 논문을 살펴주신 백형선 교수님, 차정열 교수님, 김기덕 교수님, 허경석 교수님께 깊은 감사의 말씀을 올립니다. 또한 교정학을 공부할 기회를 주시고 인도해주신 유영규 명예교수님, 손병화 명예교수님, 박영철 명예교수님, 김경호 교수님, 유형석 교수님, 이기준 교수님, 정주령 교수님, 최윤정 교수님께도 깊이 감사드립니다. 이 논문이 나오기까지 격려해주고 조언해주었던 수련동기들, 박사과정 동안 많은 도움을 주었던 섹션 후배들, 의국원들에게도 진심을 담아 감사의 마음을 전합니다.

항상 사랑으로 돌봐주시고 부족한 딸을 자랑스러워 해주시는 부모님과, 딸처럼 아껴주시고 격려해주시는 시부모님, 사랑하는 언니와 동생에게 감사의 인사를 전합니다. 그리고 무엇보다 곁에서 늘 힘이 되어주는 사랑하는 남편과 나의 두 보물 소윤이와 승윤이에게 사랑과 감사의 마음을 전하며 이 기쁨을 함께 하고자 합니다.

2015년 6 월

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Craniofacial and alveolar bone changes in young adults : A 4-year longitudinal study

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The purpose of this study is to radiographically evaluate changes of the young adult craniofacial and alveolar bone over a 4 year period. Three radiographic examinations were performed longitudinally, the first (T0) was conducted at the start of the study, the second (T1) was performed 2 years thereafter, and the third (T2) was examined at the end of the study period. The radiographic examinations included lateral cephalograms, maxillary and mandiblular anterior periapical radiographs, and bilateral posterior bitewing radiographs. The radiographs of 82 adults were obtained and measured. The following results were observed:

1. The most significant skeletal change in the craniofacial region was associated with the lengths of anterior and posterior facial height ($p<0.001$). In maxilla, both males and females showed forward movement

(p<0.05), whereas mandible showed antero−superior rotation as the length of mandibular body grew in males and postero−inferior rotation with the growth of mandibular body in females (p<0.05).

2. Upper incisor angles decreased in both males and females (p<0.05). The upper and lower incisors and molars all showed an increase of vertical distance from the reference planes in both males and females (p<0.001).

3. In regards to soft tissue changes, it turned out that the thickness of the upper and lower lips decreased (p<0.05) and the apex of nose move anteriorly in both male and female (p<0.01).

4. The average overall change of the alveolar bone was 0.27 mm and the yearly change was 0.07 mm over the 4 years period. Also, the degree of alveolar bone resorption at the starting point of the observation did not have any correlation with the alveolar bone change.

5. Between the skeletal change and the alveolar bony change, no specific correlation was examined in the first 2 years, however a weak correlation was found in some measurements during the subsequent 2 years (p<0.05).

The results of this study indicate that there were statistically significant changes in the skeletal, dental, soft tissue and physiologic changes in alveolar bone in young adults.

Key words: craniofacial changes, alveolar bone changes, skeletal changes, young adults, longitudinal study

Craniofacial and alveolar bone changes in young adults : A 4-year longitudinal study

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I. Introduction

Orthodontic objectives consist of obtaining the best aspect in facial esthetics, an efficient masticatory apparatus, stable treatment results, and healthy dental and periodontal tissues (Janson et al., 2003). For these aforementioned orthodontic objectives to be achieved, an understanding of growth changes that occur in the craniofacial structures and alveolar bone is needed. As the number of adults seeking orthodontic care has increased over the years, the importance of understanding the changes that normally take place in the supposedly "non-growing" adult craniofacial and alveolar bone has also correspondingly increased.

There are few studies that report on the craniofacial changes in adults, however these studies report contradictory findings (Kendrick and Risinger, 1967; Israel, 1973; Forsberg, 1979; Behrents, 1985; Lewis and Roche, 1988;

Tallgren and Solow, 1991; Bishara et al, 1994; Formby et al., 1994; West and McNamara, 1999). For instance, while Kendrick and Risinger (1967) and Leiws and Roche (1988) noted anterior nasal spine (ANS) moves anteriorly, Israel (1973) found there to be no changes in the position of ANS and palatal length. According to Behrents (1985), the maxillary plane inclination was found to tip posteriorly in males, whereas Forsberg (1979) reported no changes in either sex. In the mandible, Forsberg (1979) found no changes on the gonial angle and mandiblular body length, whereas Behrents (1985) found mandiblular plane angle and mandiblular body length to increase. In addition, Kendrick and Risinger (1967) observed that mandiblular prognathism increased and the mandiblular plane angle decreased, but Behrents (1985) found the mandiblular prognathism to decrease and mandiblular plane angle to increase. In regards to the dentition, Forsberg (1979) reported that maxillary incisors were upright in both sexes and madibular incisors were proclined in males, whereas West and McNamara (1999) observed madibular incisors to have no changes in both sexes.

Clinicians need to be mindful of the changes that occur in the periodontium, during the orthodontic treatment of adult patients. Orthodontic treatment may improve periodontal health, but it also holds some potential for iatrogenic harm to the periodontal tissues. Adults have a significantly greater prevalence of periodontal disease than adolescents (Schei et al., 1959; Van Der Velden, 1984). Treatment of adolescents is usually helped by growth of the jaw and the development of alveolus, whereas in adults, correction is totally a through movement of teeth in the alveolus (Harris et al., 1991). These factors may increase the iatrogenic potential of orthodontic treatment in adults. Alveolar bone loss is a more serious problem than root resorption, due to the unfavorable increase of clinical crown to root ratio and the increase of supracrestal root surface available for retention of microbial plague (Lang and Hill, 1977; Goodson et al., 1984). Furthermore, periodontal disease is a slow and continuous process, but monitoring of individual sites has led to a currently accepted hypothesis that the disease activity may occur in bursts (Lindhe et al., 1983; Sokransky et al., 1984; Goodson, 1986). Therefore, it is important to understand the normal changes in adults to identify the high periodontal disease risk patients and sites.

Several studies have found that orthodontic patients show more loss of periodontal bone support than untreated subjects of the same age. Aass and Gjermo (1992) reported that an early loss of periodontal bone support in orthodontically treated young subjects during and immediately after the orthodontic treatment could be of transient nature, and the follow-up of such results may show either a return to normal bone levels or continued progression. It is therefore important to make longitudinal and long-term observations on the alveolar bone support in subjects orthodontically treated adult patients. However, previous studies on the alveolar bone changes associated with orthodontic treatment have lacked adequate control groups of untreated subjects. They either did not observe longitudinal changes in the alveolar bone levels of untreated subjects, or that the observation period was too short to adequately compare (Sjølien and Zachrisson, 1974; Zachrisson and Alnae, 1974; Lupi et al., 1996; Nelson and Årtun, 1997; Bondemark, 1998). Therefore further longitudinal research which focuses on the alveolar bone changes during the normal function and condition as part of ageing process, in needed.

Multiple lateral cephalograms that were taken over the years can be superimposed to assess craniofacial changes. It is routinely used to monitor whether there have been changes of bone height in the intra oral radiographs and for evaluating the changes of periodontal support of teeth. Assessing the changes of alveolar bone radiographically may be superior to clinical methods because it may be difficult to keep clinical diagnostic criteria stable over time

(Suomi et al., 1968; Bondemark, 1998). In recent years, three-dimensional computed tomography (3D CT) has allowed for a more accurate evaluation of craniofacial structure and alveolar bone structures. However, due to problems such as radiation exposure, the use of CT is difficult in studies of a large number of the general public.

As such, the purpose of the present study was to radiographically evaluate changes of the young adult craniofacial and alveolar bone over a 4year period.

II. Subjects and Methods

1. Subjects

A total of 289 participated and took part in the radiographic examinations at the Institute of Craniofacial Deformity, Yonsei University College of Dentistry, Korea. Three radiographic examinations were performed longitudinally for 4 years, the first (T0) at the start of the study, the second (T1) after 2 years, and the third (T2) at the end of the study period. The radiographic examinations included lateral cephalograms, maxillary and mandiblular anterior periapical radiographs, and bilateral posterior bitewing radiographs. Of the 289 cases reviewed, 98 were excluded because of the missing radiographs or discontinuation of examinations; 75 for taking orthodontic treatment during or before examinations, 4 for plastic surgery and fracture surgery; 19 for skeletal problems due to the maxillary and mandiblular overgrowth or undergrowth, 4 for multiple missing tooth or prosthetics; 7 for poor quality radiographs. The final sample consisted of 82 adults and none of these subjects have systemic disease nor received oral cares except for simple caries treatment. Chronological age distribution of subjects and duration of observation period are as follows (Table 1).

Table 1. Chronological age distribution of subjects and duration of the observation period

	Fitst examinatin (T0) (Baseline)	Second examinatin (T1) (After 2years)	Third examinatin (T2) (After 4years)
	Mean±*SD*	Mean±*SD*	Mean±*SD*
Male (N= 62)	18.95±0.81	20.87±0.91	22.97±0.89
Female (N=20)	18.76±0.78	20.56±0.59	22.76±0.69

N: Number of subjects, *SD* : standard error of mean

2. Methods

A. Radiography

Lateral cephalograms were taken with Cranex 3+ (Soredex, Helsinki, Finland) at the Department of Orthodontics in Yonsei University Dental Hospital. The radiograph was generated at 70 kV(p) and 10 mA, with a standardized subject-to film distance. The subjects were oriented to the natural head position with their dentition in centric occlusion (CO) and lips relaxed. The radiographs were digitized with a scanner (Epson Perfection V800 Photo scanner, Jakarta, Indonesia) at 400 dpi resolution, 100 % scale and measured with Vceph 3.5™ (CybermedInc, Seoul, Korea), with a precision of 0.01 mm, 0.01°.

Intraoral radiographs were taken with Heliodent MD (Siemens, Berlin, Germany) at the Department of Oral & Maxillofacial Radiology in Yonsei University Dental Hospital. Anterior periapical radiographs were taken with the paralleling cone technique using XCP film holder including the mesial of the central incisor to the mesial of the lateral incisor and bilateral posterior bitewing radiographs were taken using Kwik-bite® film holders including the mesial of the first premolar to the distal of the first molar. The radiographs were digitized with a scanner (Epson Perfection V800 Photo scanner, Jakarta, Indonesia) at 600 dpi resolution, 100% scale and measured with Image-Pro Plus for windows version 4.5®, with a 6.5 x linear actual magnification and a precision of 0.01 mm.

B. Measurements

1) Cephalometric analysis

A conventional cephalometric approach was used to examine the data, with specific variables derived from the analyses of Bjork, Steiner, Tweed, Burstone.

(1) Landmarks (Figure 1)

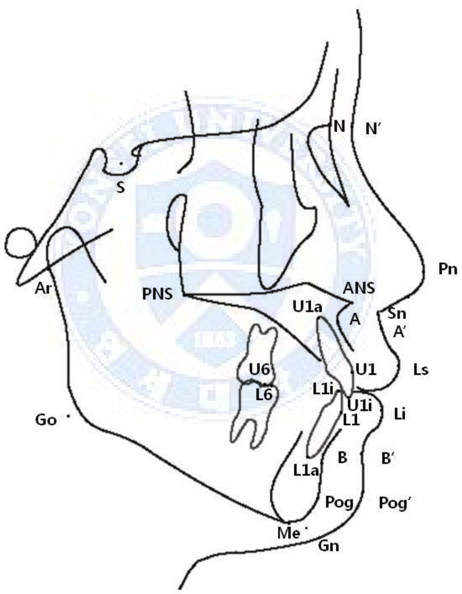

Figure 1. Cephalometric landmarks.

Sella (S), Nasion (N), Articular (Ar), Gonion (Go), Menton (Me), Gnathion (Gn), Pogonion (Po), Anterior Nasal Spine (ANS), Posterior Nasal Spine (PNS), A point (A), B point (B), Upper incisor tip (U1i), Upper incisor root (U1a), Upper molar mesiobuccal cusp tip (U6), Lower incisor tip (L1i), Lower incisor root (L1a), Lower molar mesiobuccal cusp tip (L6), Soft tissue Nasion (N′), Pronasalae (Pn), Subnasale (Sn), Soft tissue A point (A′), Upper lip (Ls), Lower lip (Li), Soft tissue B point (B′), Soft tissue pogonion (Pog′)

(2) Reference planes

2 Reference lines were set up. Firstly, the Horizontal reference (HR) plane is a straight line drawn 7 degrees inferiorly from the sella–nasin line from the sella. Secondly, the vertical reference (VR) plane is a line perpendicular to the Horizontal reference (HR) plane through sella (Figure 2).

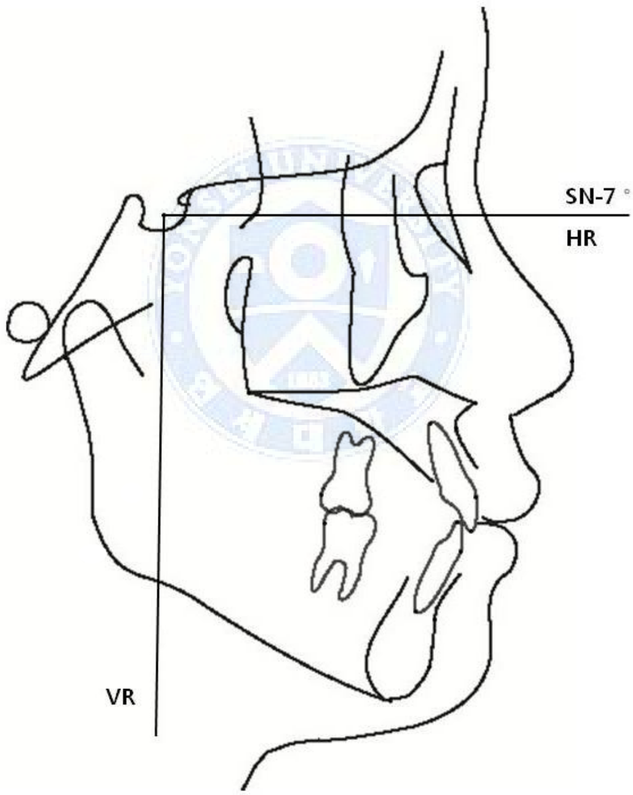

Figure 2. Cephalometric reference planes.

(3) Cephalometric measurements

Horizontal and vertical skeletal relationship, dental position and soft tissue thickness are taken into 39 cephalometric measurements (angular measurements : 7, linear measurements : 32).

a. Angular measurements (Figure 3)

7 angles that represent saddle angle, antero−posterior position of maxilla and mandible, inclination of anterior maxillary and mandibular dentition, mandibular plane angle were set up.

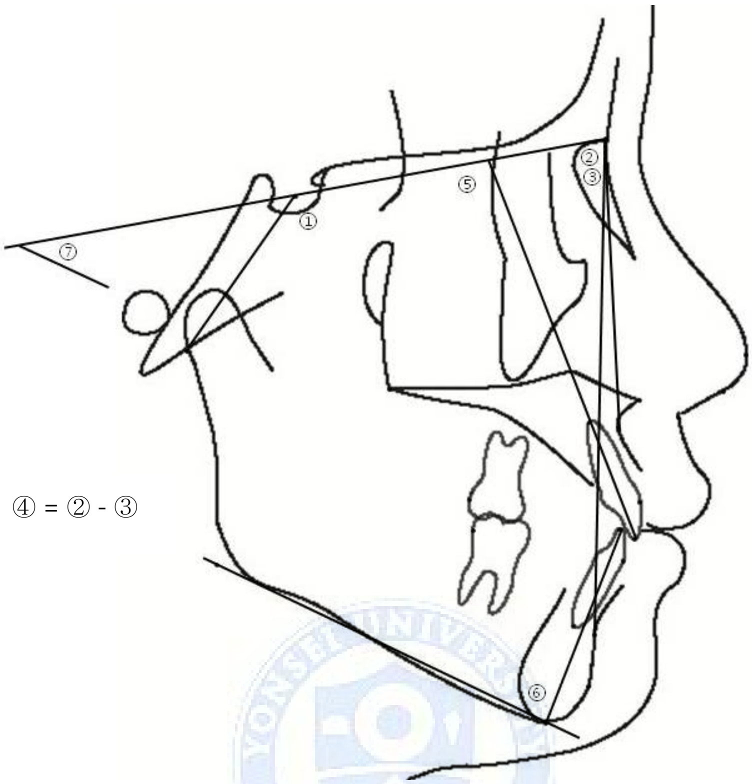

Figure 3. Angular measurements.

① Saddle angle (NSAr, degree)

② SNA (SNA, degree)

③ SNB (SNB, degree)

④ ANB difference (ANB, degree)

⑤ U1 line to SN plane angle (U1SN, degree)

⑥ IMPA (degree)

⑦ Ant. cranial base / Mn. plane (SN / GoMe, degree)

b. Linear measurements (Figure 4, Figure 5)

32 linear measurements about cranial base lengths, facial height, the position of maxilla and mandible, incisors and first molars, and soft tissue were conducted.

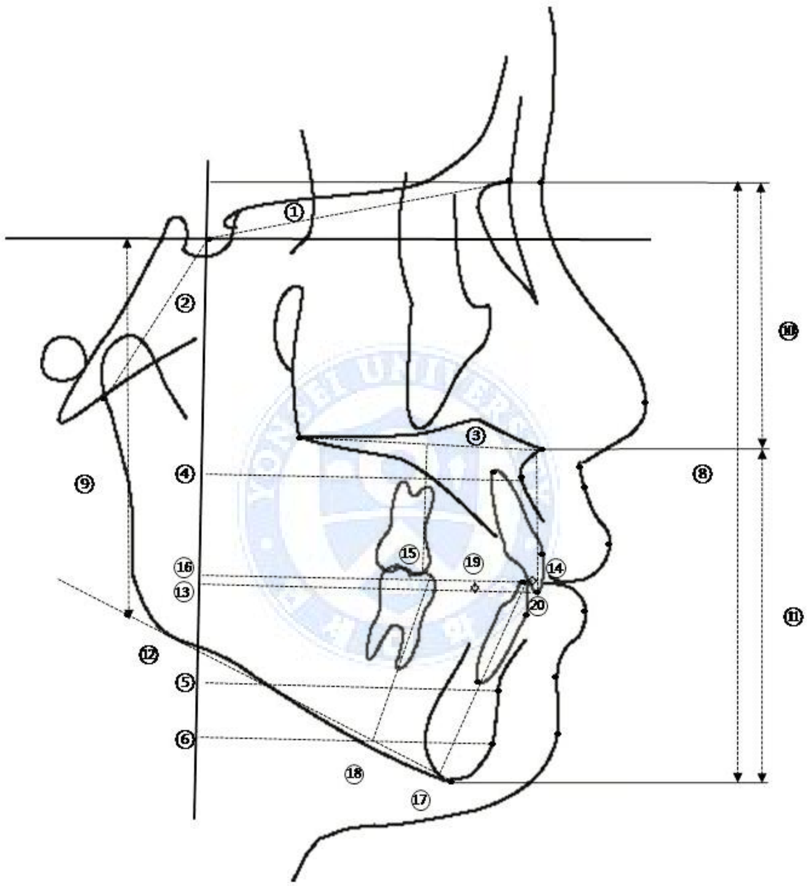

Figure 4. Linear measurements (skeletal and dental).

① Anterior cranial base (NS, mm)

② Posterior cranial base (SAr, mm)

③ PNS–ANS (mm)

④ Sella perpendicular plane to A point (VRA, mm)

⑤ Sella perpendicular plane to B point (VRB, mm)

⑥ Sella perpendicular plane to pogonion (VRPog, mm)

⑦ WITS (mm)

⑧ Anterior facial height (AFH, mm)

⑨ Posterior facial height (PFH, mm)

⑩ Upper anterior facial height (NANS, mm)

⑪ Lower anterior facial height (ANSMe, mm)

⑫ Mn. body length (Go−Me, mm)

⑬ Sella perpendicular plane to upper incisor tip (VRU1, mm)

⑭ Anterior maxillary dental height (NFU1, mm)

⑮ Posterior maxillary dental height (NFU6, mm)

⑯ Sella perpendicular plane to lower incisor tip (VRL1, mm)

⑰ Anterior mandibular dental height (MPL1, mm)

⑱ Posterior mandibular dental height (MPL6, mm)

⑲ Overbite (OB, mm)

⑳ Overjet (OJ, mm)

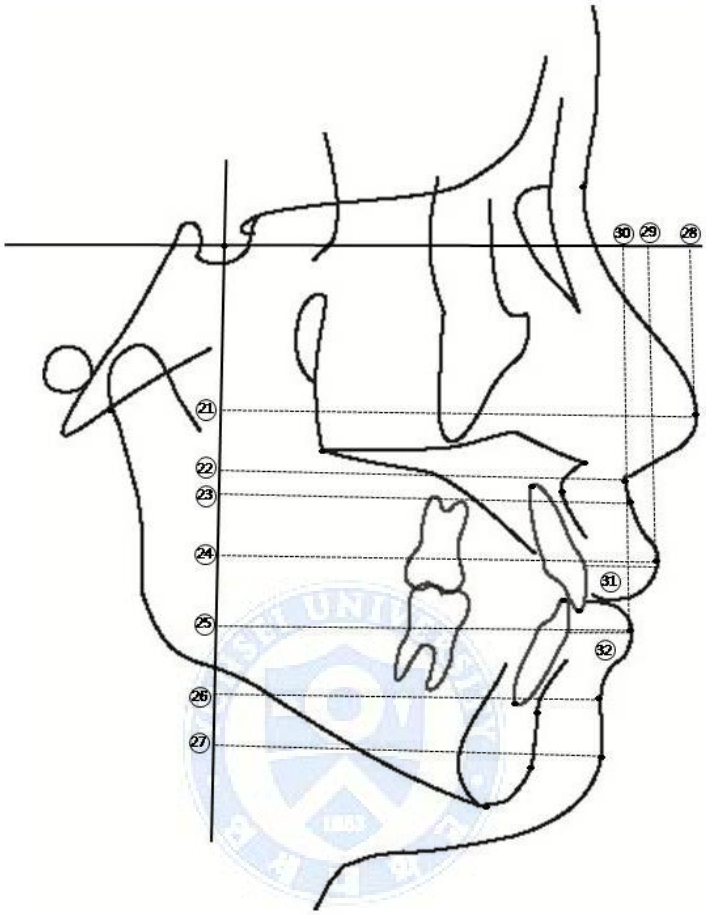

Figure 5. Linear measurements (soft tissue).

㉑ Sella perpendicular plane to pronaslae (VRPn, mm)

㉒ Sella perpendicular plane to subnasale (VRSn, mm)

㉓ Sella perpendicular plane to soft tissue A point (VRA′, mm)

㉔ Sella perpendicular plane to upper lip (VRLs, mm)

㉕ Sella perpendicular plane to lower lip (VRLi, mm)

㉖ Sella perpendicular plane to soft tissue B point (VRB′, mm)

㉗ Sella perpendicular plane to soft tissue pogonion (VRPog′, mm)

㉘ Sella horizontal plane to pronasale (HRPn, mm)

㉙ Sella horizontal plane to upper lip (HRLs, mm)

㉚ Sella horizontal plane to lower lip (HRLi, mm)

㉛ Upper lip thickness (U1Ls, mm)

㉜ Lower lip thickness (L1Li, mm)

2) Alveolar bone analysis (Figure 6)

Bite–wing radiographs were used from all four posterior quadrants including the mesial sites of first premolar to distal sites of first molar; periapical radiographs were used for maxillary and mandibular incisor legions including the mesial sites of central incisor to mesial sites of lateral incisor. Alveolar bone height was determined by measuring the difference between the cementoenamel junction (CEJ) and the crest of the alveolar bone (Baxter, 1967; Sharpe et al., 1987). The measurements were made along line parallel to the long axis of the tooth. The CEJ was defined as the junction between the root surface and the crown enamel, and the AC as the most coronal level where the periodontal membrane maintains its normal width (Björn et al., 1969). A widening of the periodontal membrane as it approaches the cervical margin of the tooth was considered as the alveolar crest height only if accompanied by some evidence of oblique resorption (Albandar et al., 1986).

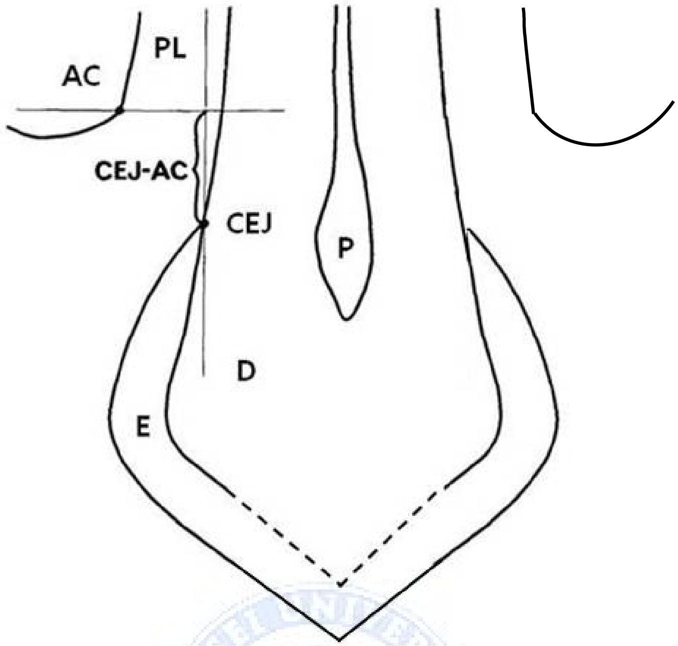

Figure 6. Alveolar bone measurement. Enamel (E), dentin (D), pulp (P), periodontal ligament (PL), alveolar crest (AC), cementenamel junction (CEJ), measured distance between CEJ and AC (CEJ−AC).

3. Statistical analysis

All variables were measured by one author and were repeated after 1 week by the same author. For determination of errors associated with such measurements, 10 subjects were selected randomly. The first measurements were selected for the statistical analysis.

All statistical evaluations were performed with SPSS version 21.0 (Statistical Package for the Social Science Inc., Chicago, IL, U.S.A.).

(1) Intra-examiner reliability was tested by a paired t-test.

(2) A normal distribution of measurements was confirmed by Kolmogorov Smirnov test.

(3) Descriptive statistics were calculated for all of the measurements taken at T0, T1, T2.

(4) A comparison by sex difference in measurements was tested using the t-test.

(5) Mean differences in measurements taken at T0, T1, T2 were analyze by 1-way analysis of variance (ANOVA).

(6) The correlation between measurements in lateral cephalogram was calculated according to Pearson's correlation analysis.

(8) The correlation between initial bone level (CEJ-AC distance at T0) and following alveolar bone changes was evaluated by Pearson's correlation analysis.

(9) The correlation between skeletal measurements and alveolar bone changes was evaluated by Pearson's correlation analysis.

III. Results

1. The intra−examiner reliability

All measurements have been recorded by a single examiner. In order to determine the errors associated with the measurements, 10 subjects were selected randomly, and their measurements were repeated 1 week following the first. The intra−examiner reliability test showed no significant differences ($p<0.05$).

2. Craniofacial changes

A. Comparison of cephalometric measurements at T0, T1, T2

The t−test values for several variables of the lateral cephalometric radiographs showed differences between male and female genders. Analyses were therefore done separately by gender.

1) Comparison of the means and mean changes at T0, T1, T2 in males (Table 2, Table 3)

Between T1 and T0, there were increases in the lengths of the anterior cranial base and posterior cranial base, the distance between ANS and PNS, anterior facial height, posterior facial height, the length of mandibular body, A point, B point, ANB, and Wits. There were decreases in mandibular plane angle and angle of upper incisor, while the angle of lower incisor increased. All four distances between upper incisor and molar from NF (ANS−PNS), and lower incisor and molar from MP (mandibular plane) increased in length. In soft tissue, the apex of nose (pronasalae) moved antero−inferiorly, and the thickness of upper and lower lips decreased.

Between T2 and T1, there was no change in the length of anterior cranial base and posterior cranial base. However the distance between ANS and PNS, posterior facial height, the length of mandibular body, A point, B point, ANB, and Wits increased consistently. The mandibular plane angle and the angle of upper incisor decreased, and the angle of lower incisor did not show a statically significant change. The distance of upper incisor and molar from NF and the distance of lower molar from MP all increased. In soft tissue, the apex of nose showed anterior growth, and upper and lower lip thicknesses decreased.

Looking at the skeletal changes throughout the entire period, an increase of cranial base length, anterior movement of maxilla and mandible, an increase of anterior and posterior facial height, and a decrease of mandibular plane angle were found. Looking at the dental changes, a decrease of upper incisor angle, an increase of distance of upper incisor and molar from NF, an increase of lower incisor angle, the distance of lower incisor from Vertical reference planes and NF, an increase of distances of the lower molar from MP were observed. In soft tissue, the anterior movement of apex of nose and a decrease of upper and lower lip thicknesses were observed.

Table 2. Comparison of measurements for male at T0, T1 and T2

Variable	T0		T1		T2		ANOVA		
	Mean	SD	Mean	SD	Mean	SD	T1-T0	T2-T1	T2-T0
Skeletal									
NSAr(°)	125.57	4.28	125.70	4.42	125.62	4.52	NS	NS	NS
NS(mm)	74.66	3.08	74.93	3.08	74.95	3.10	***	NS	***
SAr(mm)	41.98	3.55	42.31	3.56	42.44	3.59	***	NS	***
SNA(°)	81.24	2.95	81.31	2.96	81.53	2.96	NS	*	*
VRA(mm)	71.86	4.09	72.21	4.02	72.46	4.06	**	***	***
PNSANS(mm)	57.43	2.61	57.64	2.59	57.80	2.59	*	*	*
SNB(°)	78.10	3.30	78.17	3.41	78.24	3.39	*	*	*
VRB(mm)	64.41	7.20	64.45	7.35	64.54	7.39	NS	NS	NS
VRPog(mm)	64.91	8.56	65.01	8.76	65.19	8.85	*	NS	NS
ANB(°)	3.15	2.42	3.14	2.34	3.29	2.29	*	***	***
Wits(mm)	−1.10	3.62	−0.86	3.71	−0.82	3.66	**	**	**
AFH(mm)	141.17	6.56	141.99	6.72	142.23	6.87	***	***	***
PFH(mm)	96.47	6.09	97.31	6.34	97.57	6.48	***	***	***
NANS(mm)	62.49	3.23	62.70	3.19	62.71	3.27	**	NS	NS
ANSMe(mm)	77.49	5.36	78.07	5.55	85.08	5.12	***	***	***
GoMe(mm)	84.28	4.93	84.78	4.97	87.38	5.62	***	**	NS
SNGoMe(°)	32.71	5.11	32.55	5.33	32.48	5.40	*	*	*

$^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$, NS : not significant

Table 2. Continued

Variable	T0		T1		T2		ANOVA		
	Mean	SD	Mean	SD	Mean	SD	T1-T0	T2-T1	T2-T0
Dental									
U1SN(°)	102.48	6.78	101.79	6.78	101.34	6.85	***	**	***
VRU1(mm)	76.87	5.61	76.90	5.65	77.09	5.67	NS	*	NS
NFU1(mm)	34.36	2.69	34.67	2.56	34.90	2.59	***	***	***
NFU6(mm)	28.85	2.45	29.09	2.50	29.27	2.43	***	**	***
IMPA(°)	96.06	5.85	96.67	6.22	97.01	6.39	**	NS	***
VRL1(mm)	74.27	5.76	74.45	5.89	74.69	5.97	NS	**	**
MPL1(mm)	48.65	3.21	48.97	3.33	49.01	3.38	***	NS	***
MPL6(mm)	39.87	2.64	40.16	2.69	40.30	2.80	***	*	***
OB(mm)	2.26	1.87	2.30	1.94	2.27	1.91	NS	NS	NS
OJ(mm)	3.05	1.60	2.90	1.65	2.86	1.64	NS	NS	NS
Soft tissue									
VRPn(mm)	103.06	4.22	103.31	4.13	103.54	4.17	*	**	**
VRSn(mm)	87.13	4.32	87.09	4.11	87.23	4.15	NS	NS	NS
VRA' (mm)	87.90	4.58	87.65	4.37	87.68	4.46	NS	NS	NS
VRLs(mm)	92.76	5.11	92.26	5.01	92.26	5.10	NS	NS	NS
VRLi(mm)	89.15	5.98	88.90	6.19	88.92	6.16	NS	NS	NS
VRB' (mm)	79.25	7.17	79.18	7.43	79.30	7.46	NS	NS	NS
VRPog' (mm)	78.90	8.22	78.78	8.47	78.95	8.54	**	NS	NS
HRPn(mm)	47.00	4.46	47.33	4.45	47.42	4.53	**	NS	NS
HRLs(mm)	77.68	4.71	78.12	4.76	78.23	4.63	**	NS	**
HRLi(mm)	93.24	5.37	93.28	5.50	93.37	5.46	NS	NS	NS
U1Ls(mm)	15.93	1.62	15.54	1.93	15.24	1.78	*	*	***
L1Li(mm)	15.09	2.01	14.43	2.11	14.18	2.12	*	**	***

$^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$, NS : not significant

Table 3. Comparison of mean changes in measuremants for male during T0, T1 and T2

Variable	△T1-T0		△T2-T1		△T2-T0	
	Mean	SD	Mean	SD	Mean	SD
Skeletal						
NSAr(°)	0.13	1.14	−0.08	0.75	0.05	1.07
NS(mm)	0.28	0.31	0.02	0.31	0.29	0.41
SAr(mm)	0.33	0.64	0.13	0.43	0.46	0.67
SNA(°)	0.07	0.78	0.22	0.42	0.29	0.82
VRA(mm)	0.35	0.93	0.25	0.48	0.60	1.00
PNSANS(mm)	0.21	0.78	0.17	0.31	0.37	0.75
SNB(°)	0.07	0.14	0.07	0.29	0.14	0.66
VRB(mm)	0.04	0.30	0.09	0.61	0.13	1.35
VRPog(mm)	0.10	0.31	0.18	0.62	0.28	1.37
ANB(°)	0.01	0.47	0.15	0.28	0.14	0.52
Wits(mm)	0.24	0.85	0.04	0.77	0.28	1.02
AFH(mm)	0.82	0.89	0.23	0.45	1.06	0.99
PFH(mm)	0.83	0.84	0.26	0.50	1.10	0.93
NANS(mm)	0.21	0.50	0.01	0.42	0.22	0.61
ANSMe(mm)	0.58	0.88	0.31	0.50	0.89	1.04
GoMe(mm)	0.50	0.67	0.30	0.70	0.80	0.93
SNGoMe(°)	−0.16	0.33	−0.07	0.19	−0.23	0.68
Dental						
U1SN(°)	−0.70	1.21	−0.45	1.18	−1.14	1.56
VRU1(mm)	0.03	1.10	0.20	0.66	0.22	1.18
NFU1(mm)	0.31	0.56	0.23	0.49	0.54	0.74
NFU6(mm)	0.24	0.51	0.18	0.43	0.42	0.59
IMPA(°)	0.60	1.23	0.35	1.24	0.95	1.78
VRL1(mm)	0.19	1.16	0.24	0.69	0.42	1.20
MPL1(mm)	0.32	0.55	0.04	0.44	0.36	0.70
MPL6(mm)	0.29	0.56	0.14	0.54	0.43	0.77
OB(mm)	0.05	0.69	−0.04	0.49	0.01	0.77
OJ(mm)	−0.16	0.54	−0.04	0.31	−0.19	0.65

Table 3. Continued

Variable	△T1-T0		△T2-T1		△T2-T0	
	Mean	SD	Mean	SD	Mean	SD
Soft tissue						
VRPn(mm)	0.25	0.98	0.23	0.57	0.48	1.01
VRSn(mm)	−0.04	1.08	0.14	0.58	0.10	1.23
VRA' (mm)	−0.25	1.24	0.03	0.69	−0.22	1.29
VRLs(mm)	−0.49	1.64	0.00	0.91	−0.50	1.70
VRLi(mm)	−0.25	1.46	0.01	0.95	−0.23	1.47
VRB' (mm)	−0.07	1.43	0.12	0.79	0.05	1.49
VRPog' (mm)	−0.12	1.68	0.17	0.93	0.05	1.81
HRPn(mm)	0.33	0.73	0.09	0.60	0.42	0.87
HRLs(mm)	0.44	1.30	0.10	0.86	0.55	1.31
HRLi(mm)	0.04	1.64	0.10	0.92	0.13	1.66
U1Ls(mm)	−0.39	1.27	−0.30	0.85	−0.69	1.13
L1Li(mm)	−0.66	1.28	−0.25	0.75	−0.91	1.22

2) **Comparison of the means and mean changes at T0, T1, T2 in females** (Table 4, Table 5)

In females, the skeletal and dental change between T1 and T0 was similar to males, but B point moved posteriorly and the mandibular plane angle increased. In soft tissue, the apex of nose moved only inferiorly without anterior movement, and there was no significant change in the thickness of the upper and lower lips.

Between T2 and T1, skeletal change continued, but there was no statistically significant change in the most measurement values. The angle of upper incisor decreased and the distance of the upper incisor and molar from NF and lower incisor and molar from MP all increased, but the angle of lower incisor did not show a significant change. In soft tissue, the apex of nose move inferiorly and the thickness of the upper decreased, but the thickness of lower lip did not show a statistical difference.

Throughout the entire period, females showed the skeletal changes such as anterior movement of maxilla and posterior movement of mandible, the growth of anterior and posterior facial height, an increase of mandibular body length and mandibular plane angle. When it comes to dental change, a decrease of upper incisor angle and an increase of distance of the upper incisor and molar from NF and lower incisor and molar from MP were observed. In soft tissue, anterior growth of the apex of nose and a decrease of upper and lower lip thicknesses were shown.

Table 4. Comparison of measurements for female at T0, T1 and T2

Variable	T0		T1		T2		ANOVA		
	Mean	SD	Mean	SD	Mean	SD	T1-T0	T2-T1	T2-T0
Skeletal									
NSAr(°)	124.45	5.21	124.71	4.89	124.98	5.15	NS	NS	NS
NS(mm)	72.73	3.37	73.04	3.29	73.02	3.31	**	NS	NS
SAr(mm)	39.03	2.42	39.31	2.38	39.48	2.46	**	NS	NS
SNA(°)	81.06	2.56	81.06	2.54	81.17	2.59	NS	NS	***
VRA(mm)	69.83	3.31	70.14	3.36	70.24	3.45	**	NS	***
PNSANS(mm)	55.25	3.04	55.52	2.97	55.70	2.94	*	*	NS
SNB(°)	78.32	3.45	78.10	3.37	77.96	3.52	*	NS	*
VRB(mm)	63.19	7.29	62.97	7.29	62.62	7.55	NS	NS	***
VRPog(mm)	63.51	8.80	63.25	8.84	62.88	9.02	NS	NS	NS
ANB(°)	2.74	2.08	2.96	2.13	3.20	2.19	*	*	***
Wits(mm)	−2.00	2.39	−1.81	2.35	−1.47	2.39	***	NS	NS
AFH(mm)	132.92	5.67	134.15	5.60	134.58	5.41	***	NS	***
PFH(mm)	87.36	6.34	88.10	6.35	88.46	6.29	***	*	***
NANS(mm)	59.58	3.55	59.93	3.54	60.08	3.46	*	NS	NS
ANSMe(mm)	72.18	3.73	73.02	3.63	73.29	3.54	*	NS	***
GoMe(mm)	81.57	4.46	82.43	4.65	82.45	4.65	***	NS	***
SNGoMe(°)	34.37	3.43	34.48	4.31	34.49	5.98	*	NS	*
Dental									
U1SN(°)	103.66	7.87	102.57	7.69	101.56	7.70	**	**	*
VRU1(mm)	75.23	6.08	75.20	5.82	75.05	5.93	NS	NS	NS
NFU1(mm)	82.87	4.34	83.69	4.33	84.00	4.34	***	*	***
NFU6(mm)	70.50	3.84	71.14	3.78	71.50	3.58	***	*	***
IMPA(°)	93.22	8.02	94.40	8.22	95.10	7.91	**	NS	NS
VRL1(mm)	72.13	5.57	72.30	5.49	72.21	5.88	NS	NS	*
MPL1(mm)	80.17	4.74	81.06	4.66	81.61	4.62	**	*	***
MPL6(mm)	76.36	3.95	77.11	3.96	77.55	3.73	***	*	***
OB(mm)	2.15	1.45	2.06	1.25	1.81	1.23	NS	NS	NS
OJ(mm)	3.50	1.51	3.33	1.50	3.22	1.46	*	NS	NS

*$P < .05$, ** $P < .01$, ***$P < .001$, NS : not significant

Table 4. Continued

Variable	T0		T1		T2		ANOVA		
	Mean	SD	Mean	SD	Mean	SD	T1-T0	T2-T1	T2-T0
Soft Tissue									
VRPn(mm)	99.43	3.43	99.64	3.46	99.74	3.42	NS	NS	**
VRSn(mm)	83.92	3.70	84.01	3.85	83.97	3.92	NS	NS	NS
VRA' (mm)	84.39	4.02	84.27	4.03	84.14	4.12	NS	NS	NS
VRLs(mm)	89.11	5.40	88.76	5.20	88.55	5.17	*	NS	NS
VRLi(mm)	85.99	6.36	85.53	6.28	85.31	6.23	NS	NS	NS
VRB' (mm)	76.88	6.69	76.62	6.67	76.32	6.87	NS	NS	NS
VRPog' (mm)	76.93	8.13	76.50	8.14	76.17	8.22	**	NS	NS
HRPn(mm)	44.00	4.20	44.44	4.23	44.58	4.13	**	NS	NS
HRLs(mm)	72.78	4.73	73.42	4.65	73.51	4.72	*	*	NS
HRLi(mm)	88.20	4.94	88.86	4.87	88.92	4.62	NS	NS	NS
U1Ls(mm)	13.51	1.94	13.12	2.03	13.05	2.05	NS	***	*
L1Li(mm)	14.65	1.81	14.15	1.92	13.89	1.84	NS	NS	*

$^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$, NS : not significant

Table 5. Comparison of mean changes in measurements for female during T0, T1 and T2

Variable	△T1-T0		△T2-T1		△T2-T0	
	Mean	SD	Mean	SD	Mean	SD
Skeletal						
NSAr(°)	0.26	0.67	0.28	0.80	0.54	0.77
NS(mm)	0.32	0.32	−0.03	0.19	0.29	0.41
SAr(mm)	0.28	0.31	0.17	0.38	0.45	0.50
SNA(°)	0.00	0.38	0.11	0.29	0.11	0.40
VRA(mm)	0.31	0.36	0.10	0.44	0.41	0.54
PNSANS(mm)	0.27	0.41	0.18	0.26	0.45	0.52
SNB(°)	−0.23	0.47	−0.13	0.43	−0.36	0.43
VRB(mm)	−0.22	0.79	−0.35	0.94	−0.57	1.00
VRPog(mm)	−0.26	0.86	−0.37	0.97	−0.63	1.21
ANB(°)	0.23	0.31	0.24	0.35	0.47	0.37
Wits(mm)	0.18	0.62	0.34	0.69	0.52	0.76
AFH(mm)	1.23	0.63	0.43	0.94	1.66	1.24
PFH(mm)	0.74	0.53	0.36	0.66	1.10	1.02
NANS(mm)	0.35	0.55	0.15	0.28	0.50	0.67
ANSMe(mm)	0.84	0.53	0.27	0.63	1.11	0.97
GoMe(mm)	0.86	0.77	0.02	0.57	0.88	1.05
SNGoMe(°)	0.11	0.16	0.04	0.58	0.15	0.31
Dental						
U1SN(°)	−1.09	1.44	−1.01	1.06	−2.10	1.58
VRU1(mm)	−0.03	0.63	−0.15	0.62	−0.18	0.81
NFU1(mm)	0.82	0.58	0.31	0.47	1.13	0.74
NFU6(mm)	0.63	0.37	0.36	0.52	0.99	0.68
IMPA(°)	1.18	1.55	0.70	1.81	1.88	2.43
VRL1(mm)	0.18	0.66	−0.10	0.92	0.08	0.85
MPL1(mm)	0.89	0.56	0.55	0.89	1.44	1.16
MPL6(mm)	0.75	0.53	0.44	0.59	1.19	0.81
OB(mm)	−0.09	0.66	−0.25	0.85	−0.34	1.19
OJ(mm)	−0.17	0.29	−0.11	0.35	−0.28	0.45

Table 5. Continued

Variable	△T1-T0		△T2-T1		△T2-T0	
	Mean	SD	Mean	SD	Mean	SD
Soft tissue						
VRPn(mm)	0.22	0.42	0.09	0.46	0.31	0.55
VRSn(mm)	0.09	0.61	−0.03	0.45	0.06	0.75
VRA' (mm)	−0.12	0.73	−0.13	0.60	−0.25	0.79
VRLs(mm)	−0.35	1.12	−0.22	1.10	−0.57	1.17
VRLi(mm)	−0.46	1.03	−0.22	1.04	−0.68	1.29
VRB' (mm)	−0.27	0.97	−0.30	0.98	−0.57	1.24
VRPog' (mm)	−0.42	1.01	−0.34	1.01	−0.76	1.23
HRPn(mm)	0.43	0.99	0.15	0.51	0.58	1.04
HRLs(mm)	0.64	1.07	0.09	1.24	0.73	1.44
HRLi(mm)	0.66	1.17	0.06	1.10	0.72	1.64
U1Ls(mm)	−0.39	1.05	−0.07	1.21	−0.46	1.06
L1Li(mm)	−0.50	0.90	−0.25	0.85	−0.75	1.24

B. Correlation coefficients between cephalometric measurements (Table 6, Table 7, Table 8, Table 9)

The correlation, in both males and females respectively, between measurement values of lateral cephalometric radiography was examined. In males, the cranial base angle and the distance of anterior cranial base showed a correlation with anteroposterior location of maxilla and mandible. The anteroposterior location change of mandible was shown to have a high correlation with anterior and posterior facial height, especially upper facial height and mandibular plane angle. The distance of upper incisor and molar from NF had a high correlation with anterior and posterior facial height and inferior facial height. Also, in mandible, the distance between lower incisor and MP had a high correlation with lower facial height and mandibular plane angle, and the distance between lower molar and MP turned out to have a high correlation with anterior and posterior facial height and mandibular plane angle. In females, cranial base angle and length of the cranial base had correlation with anteroposterior location of maxilla and mandible. The anteroposterior location of mandible had a correlation with posterior facial height and mandibular plane angle. The anterior maxillary dental height, the anterior mandibular dental height and the posterior maxillary dental height had a correlation with anterior facial height.

Table 6. Correlation coefficients between skeletal measurements for male at T0

Variable	NSAr(°)	NS(mm)	SAr(mm)	SNA(°)	VRA(mm)	PNSANS(mm)	SNB(°)	VRB(mm)
NSAr(°)	NS	NS	NS	−0.38**	−0.45**	NS	−0.56**	−0.58**
NS(mm)	NS	NS	NS	−0.26*	0.50**	0.43**	NS	0.34**
SAr(mm)	NS	NS	NS	NS	NS	NS	NS	NS
SNA(°)	−0.38**	−0.26*	NS	NS	0.71**	NS	0.70**	0.56**
VRA(mm)	−0.45**	0.50**	NS	0.71**	NS	0.53**	0.59**	0.75**
PNSANS(mm)	NS	0.43	NS	NS	0.53**	NS	NS	NS
SNB(°)	−0.56**	NS	NS	0.70**	0.59**	NS	NS	0.91**
VRB(mm)	−0.58**	0.34**	NS	0.56**	0.75**	NS	0.91**	NS
ANB(°)	0.30*	NS	NS	0.26*	NS	NS	−0.51**	−0.57**
Wits(mm)	0.26*	NS	NS	NS	NS	0.33**	−0.46**	−0.41**
AFH(mm)	NS	0.25*	0.28*	−0.28*	NS	NS	−0.29*	NS
PFH(mm)	NS	NS	0.46**	NS	NS	NS	0.29*	0.30*
NANS(mm)	NS	0.26*	NS	−0.42*	NS	NS	−0.51**	−0.41**
ANSMe(mm)	NS	NS	NS	NS	NS	NS	NS	NS
GoMe(mm)	NS	0.42**	NS	NS	0.36*	NS	0.37**	0.49**
SNGoMe(°)	0.35**	NS	NS	−0.37**	−0.43**	0.33**	−0.64**	−0.67**

$^{*}P$ < .05, $^{**}P$ < .01, NS : not significant

Table 6. Continued

Variable	ANB(°)	Wits(mm)	AFH(mm)	PFH(mm)	NANS(mm)	ANSMe(mm)	GoMe(mm)	SNGoMe(°)
NSAr(°)	0.30*	NS	NS	NS	NS	NS	NS	0.35**
NS(mm)	NS	NS	0.25*	NS	0.26*	NS	0.42**	NS
SAr(mm)	NS	NS	0.28*	0.46**	NS	NS	NS	NS
SNA(°)	0.26*	NS	−0.28*	NS	−0.42**	NS	NS	−0.37**
VRA(mm)	NS	NS	NS	NS	NS	NS	0.36**	−0.43**
PNSANS(mm)	NS	0.33**	NS	NS	NS	NS	NS	NS
SNB(°)	−0.51**	−0.46**	−0.29*	0.29*	−0.51**	NS	0.37**	−0.64**
VRB(mm)	NS	−0.41**	NS	0.30*	−0.41**	NS	0.49**	−0.67**
ANB(°)	NS	0.84**	NS	−0.26*	NS	NS	−0.42**	0.42**
Wits(mm)	0.84**	NS	NS	NS	0.26*	−0.25*	−0.28*	NS
AFH(mm)	NS	NS	NS	0.47**	0.60**	0.82**	0.33**	0.44**
PFH(mm)	−0.26*	NS	0.47**	NS	0.26*	0.50**	0.48**	−0.55**
NANS(mm)	NS	0.26*	0.60**	0.26*	NS	NS	NS	0.31*
ANSMe(mm)	NS	−0.25*	0.82**	0.50**	NS	NS	0.40**	NS
GoMe(mm)	−0.42**	−0.28*	0.33**	0.48**	NS	0.40**	NS	−0.37**
SNGoMe(°)	0.42**	NS	0.44**	−0.55**	0.31*	NS	−0.37**	NS

$^{*}P$ < .05, $^{**}P$ < .01, NS : not significant

Table 7. Correlation coefficients between skeletal and dental measurements for male at T0

Variable	NSAr(°)	NS(mm)	SAr(mm)	SNA(°)	VRA(mm)	PNSANS(mm)	SNB(°)	VRB(mm)
U1SN(°)	−0.35**	NS	NS	0.35**	0.30**	NS	0.69**	0.62**
VRU1(mm)	−0.56**	0.32*	NS	0.71**	0.87**	0.33**	0.79**	0.86**
NFU1(mm)	NS	NS	0.30*	NS	NS	NS	NS	NS
NFU6(mm)	NS	0.29**	NS	NS	NS	NS	NS	NS
IMPA(°)	NS	NS	NS	NS	NS	0.29*	NS	NS
VRL1(mm)	−0.53**	0.35**	NS	0.64**	0.82**	0.33**	0.79**	0.87**
MPL1(mm)	NS	NS	NS	NS	NS	NS	NS	NS
MPL6(mm)	NS	NS	NS	NS	NS	NS	NS	NS
OB(mm)	NS	0.39**	0.46**	−0.27*	NS	NS	NS	NS
OJ(mm)	NS	0.49**	0.53**	NS	NS	NS	NS	NS

*P < .05, ** P < .01, NS : not significant

Table 7. Continued

Variable	ANB(°)	Wits(mm)	AFH(mm)	PFH(mm)	NANS(mm)	ANSMe(mm)	GoMe(mm)	SNGoMe(°)
U1SN(°)	0.55**	−0.51**	−0.39**	NS	NS	−0.33**	0.27*	NS
VRU1(mm)	0.77**	NS	NS	NS	NS	−0.31*	NS	0.34**
NFU1(mm)	NS	NS	0.73**	0.46**	NS	0.77**	NS	NS
NFU6(mm)	NS	NS	0.74**	0.60**	NS	0.83**	0.51**	NS
IMPA	−0.27*	0.55**	0.56**	NS	NS	NS	NS	−0.30*
VRL1(mm)	0.77*	−0.31**	NS	NS	NS	NS	NS	0.39**
MPL1(mm)	0.36**	NS	NS	NS	NS	0.71**	NS	0.52**
MPL6(mm)	NS	NS	0.69**	0.41**	NS	0.71**	NS	0.28*
OB(mm)	NS	0.39**	0.46**	NS	NS	NS	−0.42**	NS
OJ(mm)	NS	0.50**	0.53**	NS	NS	NS	−0.40**	NS

*P < .05, ** P < .01, NS : not significant

Table 8. Correlation coefficients between skeletal measurements for female at T0

Variable	NSAr(°)	NS(mm)	SAr(mm)	SNA(°)	VRA(mm)	PNSANS(mm)	SNB(°)	VRB(mm)
NSAr(°)	NS	NS	NS	−0.52*	−0.81**	NS	−0.54*	−0.63**
NS(mm)	NS	NS	NS	−0.48*	0.56*	NS	NS	NS
SAr(mm)	NS	NS	NS	NS	0.55*	NS	0.52*	0.68**
SNA(°)	−0.52*	−0.48*	NS	NS	0.46*	NS	0.80**	0.52*
VRA(mm)	−0.81**	0.56*	0.55*	0.46*	NS	NS	0.66**	0.88**
PNSANS(mm)	NS	NS	NS	NS	NS	NS	NS	NS
SNB(°)	−0.54*	NS	0.52*	0.80**	0.66**	NS	NS	0.88**
VRB(mm)	−0.63**	NS	0.68**	0.52*	0.88**	NS	0.88**	NS
ANB(°)	NS	NS	−0.63**	NS	−0.53*	NS	−0.68**	−0.83**
Wits(mm)	NS	NS	NS	NS	NS	NS	−0.68**	−0.55*
AFH(mm)	NS	NS	NS	NS	NS	NS	NS	NS
PFH(mm)	NS	NS	0.73**	NS	0.49*	NS	0.64**	0.66**
NANS(mm)	NS	NS	NS	NS	NS	NS	NS	NS
ANSMe(mm)	NS	NS	NS	NS	NS	NS	NS	NS
GoMe(mm)	NS	NS	0.50*	NS	NS	0.47*	NS	NS
SNGoMe(°)	NS	NS	−0.67**	NS	−0.47*	NS	−0.60**	−0.66**

*$P < .05$, ** $P < .01$, NS : not significant

Table 8. Continued

Variable	ANB(°)	Wits(mm)	AFH(mm)	PFH(mm)	NANS(mm)	ANSMe(mm)	GoMe(mm)	SNGoMe(°)
NSAr(°)	NS	NS	NS	NS	NS	NS	NS	NS
NS(mm)	NS	NS	NS	NS	NS	NS	0.50*	NS
SAr(mm)	−0.63**	NS	NS	0.73**	NS	NS	0.50*	−0.67**
SNA(°)	NS	NS	NS	NS	NS	NS	NS	NS
VRA(mm)	−0.53**	NS	NS	0.49*	NS	NS	NS	−0.47*
PNSANS(mm)	NS	NS	NS	NS	NS	NS	0.48*	NS
SNB(°)	−0.68**	−0.68**	NS	0.64**	NS	NS	NS	−0.60**
VRB(mm)	−0.83**	−0.55*	NS	0.66**	NS	NS	NS	−0.66**
ANB(°)	NS	0.62**	NS	−0.59**	NS	NS	−0.45*	0.58**
Wits(mm)	0.62**	NS	NS	NS	NS	−0.58**	NS	NS
AFH(mm)	NS	NS	NS	NS	0.78**	0.68**	NS	0.54**
PFH(mm)	−0.59**	NS	NS	NS	NS	NS	NS	−0.79**
NANS(mm)	NS	NS	0.78**	NS	NS	NS	0.46*	NS
ANSMe(mm)	NS	−0.58**	0.68**	NS	NS	NS	NS	NS
GoMe(mm)	−0.45*	NS	NS	NS	0.46*	NS	NS	NS
SNGoMe(°)	0.58**	NS	0.54*	−0.79**	NS	NS	NS	NS

*$P < .05$, ** $P < .01$, NS : not significant

Table 9. Correlation coefficients between skeletal and dental measurements for female at T0

Variable	NSAr(°)	NS(mm)	SAr(mm)	SNA(°)	VRA(mm)	PNSANS(mm)	SNB(°)	VRB(mm)
U1SN(°)	−0.58**	NS	NS	0.48*	0.57**	NS	0.60**	0.60**
VRU1(mm)	−0.74**	NS	0.51*	0.55*	0.88**	NS	0.77**	0.88**
NFU1(mm)	NS	NS	NS	NS	NS	NS	NS	NS
NFU6(mm)	NS	NS	NS	NS	NS	NS	NS	NS
IMPA(°)	NS	NS	NS	NS	NS	NS	NS	NS
VRL1(mm)	−0.74**	NS	NS	0.63**	0.85**	NS	0.84**	0.88**
MPL1(mm)	−0.50*	NS	NS	NS	NS	NS	NS	NS
MPL6(mm)	NS	NS	NS	NS	NS	NS	NS	NS
OB(mm)	NS	0.60**	0.50*	NS	0.49*	NS	NS	0.53*
OJ(mm)	NS	0.52*	NS	NS	NS	NS	NS	NS

*$P < .05$, ** $P < .01$, NS : not significant

Table 9. Continued

Variable	ANB(°)	Wits(mm)	AFH(mm)	PFH(mm)	NANS(mm)	ANSMe(mm)	GoMe(mm)	SNGoMe(°)
U1SN(°)	NS	NS	NS	NS	NS	NS	NS	NS
VRU1(mm)	−0.61**	NS	NS	0.50*	NS	NS	NS	−0.49*
NFU1(mm)	NS	NS	0.45*	NS	NS	NS	NS	NS
NFU6(mm)	NS	NS	0.47*	NS	NS	0.54*	NS	NS
IMPA(°)	NS	NS	NS	NS	NS	NS	NS	NS
VRL1(mm)	−0.61**	−0.45**	NS	0.52*	NS	0.46*	NS	−0.45*
MPL1(mm)	NS	NS	0.58**	NS	NS	0.69**	NS	NS
MPL6(mm)	NS	NS	NS	NS	NS	NS	NS	NS
OB(mm)	−0.56*	NS	NS	NS	NS	NS	NS	−0.61**
OJ(mm)	NS	NS	NS	NS	NS	NS	NS	NS

*$P < .05$, ** $P < .01$, NS : not significant

3. Alveolar bone change

Alveolar bony change was excluded from the measurement as an accurate difference of either one of two measurement points, cemento−enamel junction (CEJ) and alveolar crest (AC) proved difficult. In this study, a total of 8934 parts of alveolar bone were evaluated, and 835 (9.3%) among them were excluded from the measurement because it was difficult to check the measurement points accurately due to crowding, rotation, the change in angulation of the radiograph when taken.

No significant difference in mean CEJ−AC distance was found between male and female, or between contralateral tooth surfaces, or tooth. Consequently, sites from male and female as well as sites from contralateral surfaces and tooth were pooled and analyzed together.

A. Comparison of CEJ−AC distance at T0, T1, T2

1) Comparison of means in CEJ−AC distance at T0, T1, T2 (Table 10, Table 11)

The mean value and standard deviation of alveolar bone height of each site at T0, T1, T2 are shown in Table 10. In maxilla, the measured mean value of CEJ−AC distance was 0.78−1.28 mm at T0, 0.88−1.42 mm at T1, and 0.99−1.57 mm at T2. At all T0, T1, T2, the distance was shortest in the mesial side of lateral incisor and longest in the mesial side of central incisor. In mandible, the mean value of CEJ−AC distance was 0.90−1.42 mm at T0, 1.03−1.56 mm at T1, and 1.10−1.70 mm at T2. The mesial side of central incisor was longest at all T0, T1, and T2. The mesial side of first molar was shortest at T0 and T1, but was the mesial side of the first premolar at T2. The ratio of the teeth with 2mm and longer CEJ−AC distance is shown in Table 11.

Table 10. Comparison of means in CEJ-AC distance of proximal surface of maxilla and mandible dentition

Arch		T0		T1		T2		ANOVA		
Tooth	Sites	Mean	SD	Mean	SD	Mean	SD	T1-T0	T2-T1	T2-T0
Maxilla										
Central incisor	Mesial(M1U,mm)	1.28	0.38	1.42	0.37	1.57	0.38	**	**	**
	Distal(D1U,mm)	1.05	0.39	1.15	0.38	1.26	0.41	**	**	**
Lateral incicor	Mesial(M2U,mm)	0.78	0.27	0.88	0.27	1.00	0.30	**	**	**
First premolar	Mesial(M4U,mm)	1.11	0.28	1.25	0.29	1.41	0.30	**	**	**
	Distal(D4U,mm)	1.16	0.27	1.32	0.28	1.44	0.30	**	**	**
Second premolar	Mesial(M5U,mm)	1.08	0.28	1.22	0.29	1.35	0.30	**	**	**
	Distal(D5U,mm)	1.13	0.27	1.25	0.29	1.42	0.29	**	**	**
First molar	Mesial(M6U,mm)	1.13	0.32	1.25	0.34	1.42	0.34	**	**	**
	Distal(D6U,mm)	1.05	0.26	1.18	0.29	1.32	0.27	**	**	**
Mandible										
Central incisor	Mesial(M1L,mm)	1.42	0.46	1.56	0.46	1.70	0.47	**	**	**
	Distal(D1L,mm)	1.31	0.39	1.42	0.41	1.60	0.43	**	**	**
Lateral incicor	Mesial(M2L,mm)	1.00	0.44	1.18	0.54	1.27	0.47	**	*	**
First premolar	Mesial(M4L,mm)	0.91	0.31	1.04	0.34	1.10	0.32	**	*	**
	Distal(D4L,mm)	1.12	0.27	1.25	0.26	1.39	0.29	**	**	**
Second premolar	Mesial(M5L,mm)	1.03	0.25	1.16	0.25	1.29	0.27	**	**	**
	Distal(D5L,mm)	1.11	0.26	1.25	0.27	1.36	0.32	**	**	**
First molar	Mesial(M6L,mm)	1.00	0.23	1.14	0.26	1.26	0.27	**	**	**
	Distal(D6L,mm)	0.90	0.22	1.03	0.26	1.15	0.24	**	**	**

$^{*}P < .05$, $^{**}P < .01$, NS : not significant

Table 11. Percent distribution of tooth with CEJ-AC distances ≥2 mm

Arch	Tooth	T0		T1		T2	
		N	%	N	%	N	%
Maxilla	M1U	7 (161)	4.26	16 (162)	9.76	27 (161)	16.46
	D1U	3 (133)	2.44	4 (130)	3.04	8 (133)	6.10
	M2U	0 (110)	0.00	0 (111)	0.00	0 (105)	0.00
	M4U	2 (159)	1.22	5 (158)	3.05	9 (157)	5.49
	D4U	0 (148)	0.00	4 (149)	2.44	8 (145)	5.49
	M5U	1 (146)	0.61	4 (144)	3.05	10 (142)	6.71
	D5U	1 (160)	0.61	2 (158)	1.22	6 (153)	3.66
	M6U	2 (164)	1.22	4 (159)	2.44	3 (163)	1.83
	D6U	0 (162)	0.00	1 (156)	0.61	4 (160)	2.44
Mandible	M1L	31 (153)	20.12	26 (143)	18.29	38 (148)	25.61
	D1L	12 (155)	7.93	17 (144)	11.59	24 (148)	16.46
	M2L	4 (144)	2.44	5 (126)	4.27	9 (133)	6.71
	M4L	2 (140)	1.22	2 (148)	1.22	1 (118)	0.61
	D4L	1 (163)	0.61	1 (162)	0.61	7 (156)	4.27
	M5L	2 (155)	1.22	1 (157)	0.61	4 (152)	2.44
	D5L	1 (155)	0.61	2 (153)	1.22	7 (153)	4.88
	M6L	0 (158)	0.00	1 (156)	0.61	4 (158)	2.44
	D6L	1 (158)	0.61	1 (141)	0.62	2 (155)	1.22

N: Number of tooth with CEJ-AC distances ≥2 mm, ( )total number of measured sites

2) Comparison of mean changes during T0, T1, T2

(Table 12, Table 13)

The total change amount of the entire teeth for 4 years was 0.27 mm, and the yearly change amount was 0.07 mm, and each tooth showed disparities. The tooth with the most change was the mesial part of maxillary second premolar, and the one with the least change was the mesial part of mandibular first premolar.

The change amount between T1 and T0 and the one between T2 and T1 had no significant difference, and the CEJ−AC distance (the amount of alveolar bone resorption) at T0 also turned out to have no correlation with the amount of the alveolar bone change the occurred later on.

Table 12. Mean changes of CEJ-AC distance during T0, T1 and T2 of maxilla and mandible dentition

Arch	Tooth	△T1-T0		△T2-T1		Sig	△T2-T0	
		Mean	SD	Mean	SD		Mean	SD
Maxilla	**M1U(mm)**	0.15	0.08	0.13	0.07	NS	0.28	0.10
	D1U(mm)	0.11	0.13	0.12	0.15	NS	0.23	0.16
	M2U(mm)	0.10	0.11	0.12	0.09	NS	0.22	0.12
	M4U(mm)	0.14	0.12	0.16	0.11	NS	0.30	0.14
	D4U(mm)	0.16	0.09	0.12	0.10	*	0.28	0.13
	M5U(mm)	0.14	0.09	0.13	0.08	NS	0.27	0.12
	D5U(mm)	0.14	0.19	0.17	0.23	NS	0.30	0.18
	M6U(mm)	0.11	0.18	0.18	0.18	*	0.29	0.18
	D6U(mm)	0.13	0.23	0.14	0.20	NS	0.27	0.18
Mandible	**M1L(mm)**	0.14	0.07	0.14	0.11	NS	0.28	0.12
	D1L(mm)	0.11	0.16	0.18	0.21	NS	0.29	0.20
	M2L(mm)	0.18	0.30	0.10	0.25	NS	0.28	0.14
	M4L(mm)	0.13	0.16	0.08	0.21	NS	0.20	0.21
	D4L(mm)	0.13	0.07	0.15	0.12	NS	0.27	0.14
	M5L(mm)	0.13	0.08	0.12	0.09	NS	0.26	0.11
	D5L(mm)	0.14	0.10	0.13	0.09	NS	0.27	0.11
	M6L(mm)	0.14	0.10	0.12	0.13	NS	0.26	0.15
	D6L(mm)	0.11	0.16	0.15	0.13	NS	0.26	0.12

*$P < .05$, NS : not significant

Table 13. Correlation coefficients of mean changes of CEJ-AC distance during T0, T1 and T2 with initial bone resorption (CEJ-AC distance at T0)

Arch	Tooth		△T1-T0	△T2-T1	△T2-T0
Maxilla	**M1U(mm)**	**T0**	NS	NS	NS
	D1U(mm)	**T0**	−0.32*	NS	NS
	M2U(mm)	**T0**	NS	NS	NS
	M4U(mm)	**T0**	NS	NS	NS
	D4U(mm)	**T0**	NS	NS	NS
	M5U(mm)	**T0**	NS	NS	NS
	D5U(mm)	**T0**	NS	NS	NS
	M6U(mm)	**T0**	NS	NS	NS
	D6U(mm)	**T0**	−0.34*	NS	NS
Mandible	**M1L(mm)**	**T0**	NS	NS	NS
	D1L(mm)	**T0**	NS	NS	NS
	M2L(mm)	**T0**	NS	NS	NS
	M4L(mm)	**T0**	NS	NS	NS
	D4L(mm)	**T0**	NS	NS	NS
	M5L(mm)	**T0**	NS	NS	NS
	D5L(mm)	**T0**	NS	NS	NS
	M6L(mm)	**T0**	NS	NS	NS
	D6L(mm)	**T0**	NS	NS	NS

*$P < .05$, NS : not significant

4. Correlation coefficients of CEJ−AC distances with cephalometric measurements

During the period between T0 and T1, no particular correlation was spotted between skeletal change or anteroposterior change of tooth and alveolar bony change. It turned out, between T1 and T2, that there was a weak correlation between some skeletal change and anteroposterior change of tooth and alveolar bony change. In maxillary central incisor in particular, it turned out that CEJ−AC distance of incisor increased as the maxillary incisor angle decreased and the distance between upper incisor tip and NF height increased (Table 14, Table 15, Table 16).

Table 14. Correlation coefficients of CEJ-AC distances with cephalometric measurements during △T1-T0

Tooth	SNA	SNB	ANB	Wits	AFH	PFH	NANS	ANSMe	GoMe	SNGoMe
M1U(mm)	NS	NS	NS	0.24**	NS	NS	NS	NS	NS	NS
D1U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M2U(mm)	NS	−0.28**	NS	NS	NS	NS	NS	NS	NS	NS
M4U(mm)	0.22*	0.26**	NS	NS	NS	NS	NS	NS	NS	NS
D4U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M5U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D5U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M6U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D6U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M1L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D1L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M2L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M4L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D4L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M5L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D5L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M6L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D6L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

$^{*}P < .05$, $^{**}P < .01$, NS : not significant

Table 14. Continued

Tooth	U1SN	VRU1	NFU1	NFU6	IMPA	VRL1	MPL1	MPL6	OB	OJ
M1U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D1U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M2U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M4U(mm)	NS	0.22*	NS	NS	NS	NS	NS	NS	NS	NS
D4U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M5U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D5U(mm)	0.24*	NS	NS	NS	NS	NS	NS	NS	NS	NS
M6U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D6U(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M1L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D1L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M2L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M4L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D4L(mm)	NS	NS	NS	NS	−0.25*	NS	NS	NS	NS	NS
M5L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D5L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M6L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D6L(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*$P < .05$, NS : not significant

Table 15. Correlation coefficients of CEJ-AC distances with cephalometric measurements during △T2-T1

Tooth	SNA	SNB	ANB	Wits	AFH	PFH	NANS	ANSMe	GoMe	SNGoMe
U1M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U1D(mm)	-0.25^{***}	NS	NS	NS	NS	NS	NS	NS	-0.32^{**}	NS
U2M(mm)	NS	0.25^{**}	-0.36^{***}	-0.35^{**}	NS	NS	NS	NS	NS	NS
U4M(mm)	NS	NS	NS	NS	-0.23^{**}	NS	-0.34^{**}	NS	NS	NS
U4D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	-0.24^{**}	NS
U5M(mm)	0.39^{***}	0.31^{**}	NS	NS	NS	NS	-0.24^{**}	0.25^{**}	NS	NS
U5D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U6M(mm)	0.35^{**}	NS	0.27^{**}	NS	NS	NS	NS	NS	NS	NS
U6D(mm)	NS	0.31^{**}	-0.29^{**}	NS	NS	NS	NS	NS	NS	NS
L1M(mm)	NS	NS	NS	-0.28^{**}	NS	NS	NS	NS	NS	NS
L1D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L2M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L4M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L4D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L5M(mm)	NS	NS	NS	0.31^{***}	NS	NS	NS	NS	NS	NS
L5D(mm)	NS	NS	NS	NS	NS	NS	NS	0.23^{**}	NS	NS
L6M(mm)	0.25^{**}	NS	NS	NS	NS	NS	-0.22^{**}	NS	NS	NS
L6D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

** $P < .01$, $^{***}P < .001$, NS : not significant

Table 15. Continued

Tooth	U1SN	VRU1	NFU1	NFU6	IMPA	VRL1	MPL1	MPL6	OB	OJ
U1M(mm)	-0.21^{**}	0.31^{***}	NS	NS	NS	0.27^{**}	NS	NS	NS	NS
U1D(mm)	-0.25^{**}	NS	0.45^{**}	NS	NS	NS	NS	NS	NS	NS
U2M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U4M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U4D(mm)	0.26^{**}	NS	NS	-0.26^{**}	NS	NS	NS	NS	NS	NS
U5M(mm)	0.27^{**}	0.29^{**}	-0.21^{**}	NS	NS	NS	NS	NS	NS	NS
U5D(mm)	NS	NS	NS	NS	NS	NS	NS	0.24^{**}	NS	NS
U6M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U6D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L1M(mm)	NS	NS	NS	-0.34^{***}	NS	NS	NS	NS	NS	NS
L1D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L2M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L4M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L4D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L5M(mm)	NS	NS	NS	NS	NS	NS	NS	-0.27^{**}	NS	NS
L5D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L6M(mm)	NS	NS	NS	NS	NS	NS	NS	0.25^{**}	NS	NS
L6D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

** $P < .01$, $^{***}P < .001$, NS : not significant

Table 16. Correlation coefficients of CEJ-AC distances with cephalometric measurements during △T2-T0

Tooth	SNA	SNB	ANB	Wits	AFH	PFH	NANS	ANSMe	GoMe	SNGoMe
U1M(mm)	NS	NS	0.25*	NS	NS	NS	NS	NS	NS	NS
U1D(mm)	−0.27*	−0.29*	NS	NS	NS	NS	0.37**	NS	−0.26*	NS
U2M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U4M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U4D(mm)	NS	NS	NS	NS	NS	−0.23*	NS	−0.31**	NS	NS
U5M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U5D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U6M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	−0.25*
U6D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L1M(mm)	NS	NS	NS	−0.26*	NS	NS	0.24*	NS	NS	NS
L1D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L2M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L4M(mm)	NS	NS	NS	−0.25*	NS	0.27*	NS	NS	NS	NS
L4D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L5M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L5D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L6M(mm)	NS	NS	NS	−0.45*	NS	NS	NS	NS	NS	NS
L6D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*$P < .05$, ** $P < .01$, NS : not significant

Table 16. Continued

Tooth	U1SN	VRU1	NFU1	NFU6	IMPA	VRL1	MPL1	MPL6	OB	OJ
U1M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U1D(mm)	−0.26*	NS	0.25**	NS	NS	NS	NS	NS	NS	NS
U2M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U4M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U4D(mm)	NS	NS	NS	NS	NS	−0.23*	NS	NS	NS	0.22*
U5M(mm)	0.22*	NS	NS	NS	NS	NS	NS	NS	NS	NS
U5D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
U6M(mm)	0.22*	NS	NS	NS	NS	NS	NS	NS	NS	0.23*
U6D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L1M(mm)	NS	NS	NS	−0.32**	NS	NS	NS	NS	NS	NS
L1D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L2M(mm)	0.33**	NS	NS	NS	NS	NS	NS	NS	NS	NS
L4M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L4D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L5M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L5D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L6M(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L6D(mm)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*$P < .05$, ** $P < .01$, NS : not significant

IV. Discussion

A vast majority of people who receive orthodontic treatment are children and juveniles, and since the period in which the most growth occur is at the late teenage years, and accordingly, the studies on growth change have been focused on pre-puberty or puberty. More recently, the studies on the change occurring during the adult period are also being conducted in alignment with the growing number of adult patients. However, the previous studies that were done on adult subjects had some problems namely; the number of the study subjects were too small, the age range was too wide, interval between observations were too long, or that the examination condition was not appropriately standardized. Therefore, this study included only the subjects aged from 18 to 19 in the beginning of the study, and on all the study subjects, examination intervals were set to 3 times per every 2 years. Also, the radiographic examinations were done in one place, Yonsei University Dental Hospital, by using a standardized method and one examiner conducted all the measurements. Thus, errors caused by the utilizing different examination and measuring methods could be minimized.

The most significant skeletal change in the craniofacial region was associated with the lengths of anterior and posterior facial height. In both males and females, anterior and posterior facial height increased. However, in males, mandibular plane angle decreased due to greater growth of posterior facial height than anterior facial height. In females, mandibular plane angle increased due to greater growth of anterior facial height than posterior facial height. The increase in anterior facial height in both males and females is mostly due to an increase of the inferior facial height. This result coincided with the result of the previous study (Forsberg, 1979; Sarnas and Solow, 1980; West and McNamara, 1999).

In maxilla, both males and females showed the forward movement and the increased length, whereas the mandibular changes differed by gender. In males, mandible showed antero−superior rotation as the length of mandibular body grew. In females, however, postero−inferior rotation of mandible was shown along with the growth of mandibular body. It is thought that difference of the rotation of mandible in males and females is due to the disparity of antero−posterior facial height growth mentioned above.

In cranial base, more specifically the cranial base angle, both males and females did not show any statistically significant changes over 4 years, and this result coincided with the result of the previous studies that cranial base angle does not change after the age of 20 (Björk, 1955; Tallgren, 1974). In regards to the cranial base length, males showed an increase in both anterior and posterior cranial base lengths. In females, the length of posterior cranial base continuously increased for 4 years, but anterior cranial base length actually showed the decreasing tendency between the second examination and the third examination (T2−T1). However, in both males and females, there was no statistically significant cranial base changes noted during this period (T2−T1).

Upper incisor angles decreased in both males and females which coincided with the previous studies that reported the uprighting of the maxillary incisors in both genders (Forsberg, 1979; Behrents, 1990; Bishara et al., 1994), but differed from the study by West and McNamara (1999) who found the uprighting incisors only in the female group. For lower incisors angles, both males and females showed the increase in the first 2 years (T1−T0), but showed no significant difference in subsequent 2 years thereafter (T2−T1). This finding differed from the result of the previous study that there was no change on the incisor angle of both males and females (Bishara et al., 1994). The upper and lower incisors and molars all showed an increase of the vertical distance from reference planes, and this confirmed the fact that teeth were constantly erupting. Also, the vertical location change of teeth was closed associated with facial height, and this result coincided with the previous study that the continuous increase of inferior facial height was due to not only the skeletal growth but also to the eruption of teeth occurring constantly even after the completion of occlusion (Forsberg et al., 1991; Tallgren and Solow, 1991).

In regards to the soft tissue changes, for males, it turned out that the thickness of the upper and lower lips constantly decreased, and the apex of nose move antero-posteriorly for the first 2 years (T1-T0), and moved anteriorly for the subsequent 2 years afterwards (T2-T1). In females, for the first 2 years (T1-T0) the apex of nose moved inferiorly and there was no thickness change in the upper and lower lips, but for the subsequent 2 years afterwards (T2-T1), not only was there a change of nose, but there was also a decreased thickness of the upper lip. These findings coincides with the study result by Formby et al. (Formby et al., 1994). Soft tissue change like this definitely needs be taken into consideration when treatment planning. Thus straight soft tissue profiles and retruded lip position should be avoided at a young age. The soft tissue changes arise mainly due to changes in underlying skeletal morphology. This is most obvious during puberty when the growth is most active. In adults, as there are relatively minimal skeletal changes, other causes of soft tissue changes play an important role such as weight gain and loss, posture change, muscular weakening by aging and so on.

Lateral cephalometric radiography measurements showed that the absolute values were smaller in females than in males. However progressively greater changes were noted throughout the observation period. This coincides with the study that the growth of female starts earlier than that of male and the period of active growth finishes earlier in female, however during the adult period, skeletal changes starts earlier and greater in female (Akgül et al., 2002). Also, there were many values where standard deviation was larger in females, and it was thought that in female cases, the individual difference should be more considered when predicting the skeletal change of adult.

As far as the change in alveolar bone is concerned, the purpose of this study was to find the relationships between the skeletal change and associated alveolar bone resorption and also to assess the relationships between alveolar bone height at the starting point of observation and bone resorption later on. In the previous studies, the yearly average alveolar bone loss amount of normal adult is reported to range from 0.07 mm to 0.11 mm (Goodson et al., 1982; Albandar et al., 1986; Suomi et al., 1971; Rohner et al., 1983), it was reported that the person who received orthodontic treatment underwent more alveolar bone resorption than the person who received no orthodontic treatment by 0.2 mm–0.5 mm approximately (Baxter, 1967; Zachrisson et al.; 1974, Hollender et al., 1980; Ögaard, 1998). In this study, an average overall change for 4 years was 0.27 mm and the yearly change was 0.07 mm.

According to Janson et al., CEJ–AC distance could be one standard which decides whether there is an alveolar bone loss. However, an increase of this distance does not necessarily mean that an alveolar bone loss surely occurred, and a CEJ–AC measurement under 2 mm was normal based on the previous studies which found the distance from the CEJ to AC to range from 0 to 2 mm in person with no history or signs of periodontal disease (Janson et al., 2003; Hausmann et al., 1991). In this study, in the first examination (T0) 2.51 % of the site showed 2mm or greater CEJ–AC measurement, 3.59 % in the second examination (T1), and 6.37 % in the third examination (T2). The mesial of lower central incisor was the most common area that showed > 2 mm CEJ–AC distance followed by the distal of lower central incisor and mesial of upper central incisor. The above result is similar to that of the previous study which said that CEJ−AC distance is longer in upper and lower incisor and upper molar (Schei et al. 1959, Ramfjord 1961). However, over the 4−year observation period, no site underwent > 2 mm alveolar bone resorption. Therefore, it is more accurate to say that an increase of CEJ−AC distance is not a resorption by periodontal disease but a physiological change. Upper and lower incisors required more thorough periodontal management because alveolar bone resorption occurs most commonly in these regions. The alveolar resorption in anterior incisors often results in the loss of interdental papilla, creating spaces interdentally witch is known as the black triangle, one of the most common post−operative aesthetic complaints of orthodontic patients.

There was no statistically significant difference between the mean change of CEJ−AC distance in the first 2 years (T1−T0) and in the subsequent 2 years (T2−T1) afterwards. Also, CEJ−AC distance at the first examination (the degree of alveolar bone resorption at the starting point of observation) did not have any correlation with alveolar bone change. This indicates that even if the alveolar bone resorption is severe, it doesn't necessarily mean severe alveolar bone loss is going to occur consistently unless the periodontal disease is ongoing. It could be said, therefore, that previous alveolar bone resorption is not a risk factor causing alveolar bone resorption during the orthodontic treatment, and that an oral hygiene management is rather a more important factor (Suomi et al., 1971).

Between skeletal change and alveolar bony change, no specific correlation was examined for the first 2 years (T1−T0), and a weak correlation was found on some measurement for the subsequent 2 years (T2−T1) afterwards. According to the previous study, the larger the mandibular plane angle was, the thinner the alveolar bone of mandibular anterior teeth was and also the lower the density of maxillary and mandibular buccal alveolar bone density

(Kim et al., 2010; Ozdemir et al., 2014). Therefore, it was expected that the larger the mandibular plane angle, the more alveolar bone resorption would occur. However, it turned out that there was no correlation between the mandibular plane angle and the degree of alveolar bone resorption. However, antero-posterior and vertical change of tooth had a partial correlation with alveolar bony change. Especially in upper incisors, CEJ-AC distance became greater as the angle decreased and the distance from NF to the incisal tip increased. It is thought that an increase of CEJ-AC distance could be caused not only by alveolar bone resorption but also by the lack of regeneration of alveolar bone during continuous tooth eruption during adulthood.

There are several limitations in this study. First, although an attempt was made to include subjects with narrowly defined age ranges and consistent examination intervals, the male female ratio was not able to be adjusted to be identical. Second, the case of which ANB and Wits deviated from the normal range was excluded from the study subjects since the skeletal change could be different depending on the skeletal type, however the vertical skeletal type was not considered because there were inadequate number of subjects. Third, any error from radiographic examination cannot be ruled out completely, because the bone change was very small and the study period was only limited to 4 years. Additional research is required to compensate for such limitations and to gain a more accurate understanding of normal physiological changes of adult craniofacial and alveolar bone.

V. Conclusion

The purpose of this study was to radiographically evaluate changes of the young adult craniofacial and alveolar bone over a 4 year period. The following results were observed:

1. The most significant skeletal change in the craniofacial region was associated with the lengths of anterior and posterior facial height ($p<0.001$). The growth of posterior facial height was greater than anterior facial height in males, but the reverse was observed in females. In maxilla, both males and females showed forward movement ($p<0.05$), whereas mandible showed antero-superior rotation as the length of mandibular body grew in males and postero-inferior rotation with the growth of mandibular body in females. The cranial base angle did not show any statistically significant changes, whereas cranial base length showed an increase in both males and females ($p<0.05$).

2. Upper incisor angles decreased in both males and females ($p<0.05$). Lower incisor angles increased in males ($p<0.05$), whereas there was no significant difference in females. The upper and lower incisors and molars all showed an increase of vertical distance from the reference planes in both males and females ($p<0.001$).

3. In regards to soft tissue changes, it turned out that the thickness of the upper and lower lips decreased ($p<0.05$) and the apex of nose moved anteriorly in both male and female ($p<0.01$).

4. Looking at changes in the alveolar bone, the average overall change over the 4 year periods was 0.27 mm and the yearly change was 0.07 mm. There was no statistically significant difference between the mean

change of CEJ-AC distance in the first 2 years and in the subsequent 2 years thereafter. Also, the degree of alveolar bone resorption at the starting point of the observation did not have any correlation with the alveolar bone change.

5. Between the skeletal change and the alveolar bony change, no specific correlation was examined in the first 2 years, however a weak correlation was found in some measurements during the subsequent 2 years ($p<0.05$).

The results of this study indicate that there were statistically significant changes in the skeletal, dental, soft tissue and physiologic changes in alveolar in young adults.

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국문요약

젊은 성인에서의 두개안면부와 치조골 변화
: 4년간 종단적 연구

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본 연구의 목적은 교정치료를 받지 않은 일반 성인의 두개악안면부 골격과 치조골의 4 년간 변화를 평가하는 것이다. 연구 시작 시점에 첫 촬영 (T0), 첫 촬영 2 년 후 두 번째 촬영 (T1), 두 번째 촬영 2 년 후 세 번째 촬영 (T2)의 총 3 회의 방사선 검사가 이루어졌다. 성인 82 명의 측모 두부 방사선 규격 사진과 상하악 전치부 치근단 방사선 사진과 좌우 구치부 교익 방사선 사진의 분석을 통하여 다음과 같은 결과를 얻었다.

1. 두개악안면부에서 변화가 가장 컸던 부분은 전안면 고경과 후안면 고경의 길이였다 ($p<0.001$). 상악의 경우 남녀 모두 전방으로 이동하였으나 ($p<0.05$), 하악의 경우 남성은 하악체의 길이가 증가하면서 전상방 회전되고, 여성은 하악체의 길이가 증가하면서 후하방 회전되었다 ($p<0.05$).

2. 치성 변화에서는 남녀 모두 상악 전치의 각도는 감소하였다 ($p<0.05$). 하악 전치의 각도는 남성에서는 증가하고 여성에서는 유의한 변화를 보이지 않았다. 상하악 전치와 제 1 대구치의 수직 거리는 증가하였다 ($p<0.001$).

3. 연조직에서는 남녀 모두 상하순 두께가 지속적으로 감소하고 ($p<0.05$), 비첨부는 전방 이동하였다 ($p<0.01$).

4. 치조골 변화에 있어서는 전체 치아의 백악법랑경계와 치조정 사이의 거리는 4 년간 0.27 mm, 연 0.07 mm 변화하였다. 관찰 시작 시점의 백악법랑경계에서 치조정까지의 거리도 이후 발생하는 치조골 변화량과는 상관관계가 없는 것으로 나타났다.

6. 골격 형태 변화와 치조골 변화 사이에는 특별한 상관관계를 확인할 수 없었고, 치아의 전후방적 수직적 위치 변화는 치조골 변화와 약한 상관관계가 있었다 ($p<0.05$).

이상의 연구결과, 남녀 모두 변화의 양은 적었으나 성인 초기에서 골격과 치아 및 연조직의 지속적인 변화와 치조골 생리적인 변화는 지속된다는 사실을 확인할 수 있었다.

핵심이 되는 말: 두개악안면부 변화, 골격 변화, 연조직 변화, 치조골 변화, 성인, 종단적 연구